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Development of Novel Connection Control Method for Small Scale Solar - Wind Hybrid Power Plant

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Abstract: Solar power systems are rapidly increasing in many countries on the world but the power conditioner system for these applications can only provide power based on what the solar array can immediately generate from the sun. So, the utilization rate of the power conditioner in solar power system is low because of depending on the weather. We can use a hybrid power system including small scale wind turbine and photovoltaic (PV) cell to improve the utilization rate of the power conditioner because the small scale wind power generating system can operate the power conditioner at night and also can use the remaining capacity of power conditioner during daytime. However, the power conditioner of PV cell cannot control optimally the wind turbine due to the output characteristics of wind turbine and PV cell are different. Thus, we researched method that the small scale wind power generating system can connect to the off grid and grid tie power conditioner of solar panel by emulating technical characteristic of PV cell. In previous research [1], we verified that the PV cell emulating system can operate the off grid power conditioner in the stand-alone mode by an actual experiment as well as preliminary method for connecting the emulating system with PV cell. In this paper, we introduce technique solution for grid tie PV cell emulating system in the stand alone mode and propose a novel control design for off grid PV cell emulating system in series connection mode.

Keywords: PV cell emulating system, Power conditioner, Virtual damping control

1. Background

The utilization rate of the power conditioner in solar power system is low because operation of PV cell depends on the weather. Adding the small scale wind power generating system to the existing solar power generation system can increase the utilization rate of power conditioner. However, the power conditioner for PV cell cannot control optimally the wind turbine due to output characteristic of wind turbine and PV cell are different. So, we studied the method that the small scale wind power generating system can connect to the power conditioner for solar panel by emulating technical characteristic of PV cell.

2. Methods

2.1. Grid tie PV cell emulating system in the stand alone mode

a. Configuration of grid tie PV cell emulating system in the stand alone mode

The completed grid tie PV system with power conditioner including DC/DC converter and grid tie DC/AC inverter is shown in Fig.1. The PV array is connected to the DC/DC converter in boost mode which is used to perform the maximum power point tracking (MPPT). The electrical energy at the output terminals of the PV array is injected into the utility grid by grid tie DC/AC inverter.

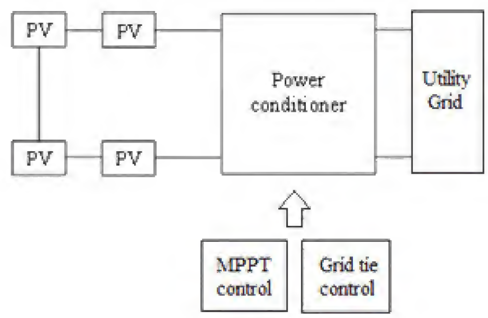

Fig. 1: Grid tie PV system

The configuration of PV cell emulating system composes of the small scale wind power generating system, a battery and the power convertor circuit. The small scale wind power generating system charges the battery. The power convertor circuit detects current flowing into the power conditioner and operates it by control system.

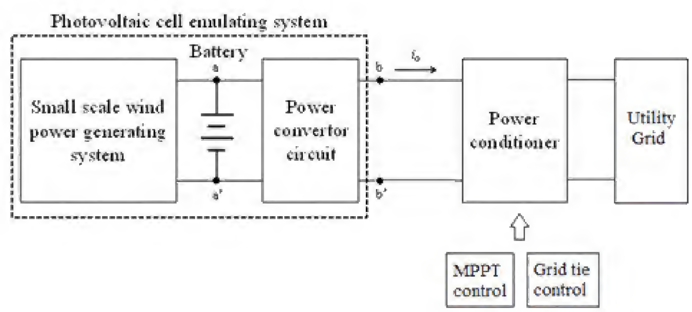

Fig. 2: PV cell emulating system in the stand alone mode

When PV cell cannot receive sunlight, only the small scale wind power generating system operates the power conditioner. This mode is called in the stand alone mode (Fig. 2). In this mode, PV cell is bypassed in order to avoid that it becomes the load.

b. Model equation of stand-alone mode

In this mode, the power convertor circuit emulates the technical characteristics of actual PV cell so that PV cell emulating system can connect to the DC/DC converter to perform the MPPT control. PV cell characteristic is modeled by two linear

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equations in Fig. 3. Maximum power point voltage V_{max} is determined considering the operating voltage of the power conditioner while maximum power point current I_{max} is calculated by dividing generated power from the small scale wind turbine by V_{max}. The open voltage and short current are calculated by multiplying correlative constant factors by maximum power point voltage and maximum power point current.

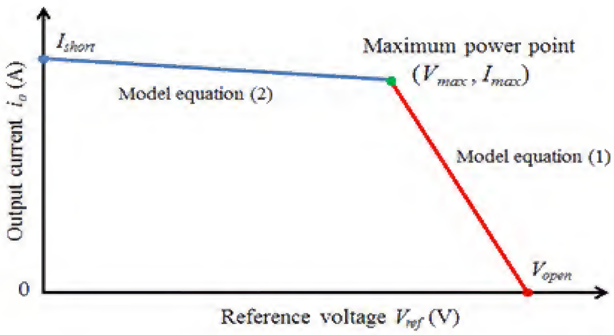

Figure 3. Model equation of PV cell characteristic

Two linear equations (1) and (2) are determined as follows:
with V_{max} and I_{max} are maximum power point voltage and

$$V_{ref} = -\frac{V_{open} - V_{max}}{I_{max}} i_o + V_{open} \tag{1}$$

$$V_{ref} = -\frac{V_{max}}{I_{short} - I_{max}} i_o + \frac{V_{max} I_{short}}{I_{short} - I_{max}} \tag{2}$$

current; V_{open} is open voltage; I_{short} is short current; V_{ref} calculated by linear model equations is reference voltage to PI controller; i_o is output current of PV cell emulating system.

In this paper, an example of linear model equations is used in Fig. 4 with the parameters in table 1.

Table 1: Parameter for example of linear model equations

Parameter	Value
Maximum power point voltage V_{max}	100 V
Maximum power point current I_{max}	0.8 A
Open voltage V_{open}	116.4 V
Short current I_{short}	0.9 A

c. Power convertor circuit in the stand alone mode

In the first stage, the small scale wind power generating system charges the battery. After the battery is fully charged, it disconnects with the small wind turbine. So, the power convertor circuit and the battery are used to operate the power conditioner. In this study, a bi-directional chopper circuit is used as the power convertor circuit. Fig. 4 shows the configuration of the power convertor circuit in the stand alone mode. In this mode, the bi-directional chopper circuit is used as the boost chopper which increases the battery voltage to operating voltage of the power conditioner. Firstly, the current sensor detects the output current i_o flowing into the power conditioner. The comparator determines the used model equation to calculate the reference voltage v* by comparing output current value with current value of the intersection of model equations. Then PI controller and career comparison control the output voltage v_o to the voltage reference by altering the duty factor.

Power is converted by the switching control and the ripple can be suppressed by the output filter inductor L_2 and capacitor C_2. The resistor R prevents the inrush current flowing into the capacitor C_2 and the internal capacitor of power conditioner.

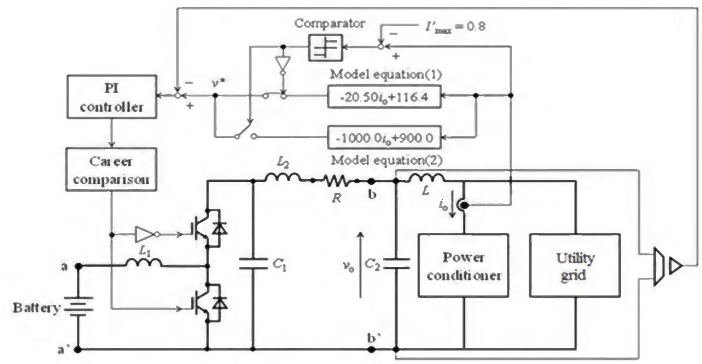

Fig. 4: Power convertor circuit in the stand alone mode

2.2. Off grid PV cell emulating system in series connection mode

a. Configuration of off grid PV cell emulating system in series connection mode

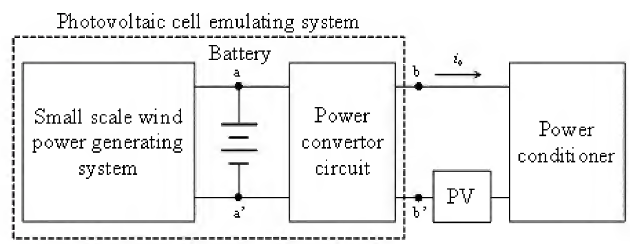

Fig. 5: PV cell emulating system in series connection mode [1]

When sunlight appears, both the small scale wind power generating system and PV cell operate the power conditioner. The configuration of off grid PV cell emulating system in series connection mode is shown in Fig. 5.

In the series-connection mode, PV cell is connected with the emulating system in series. So, the maximum power point current value of PV cell and the emulating system output current must be matched (Fig. 6). If otherwise, the power conditioner cannot control the input power to the maximum power.

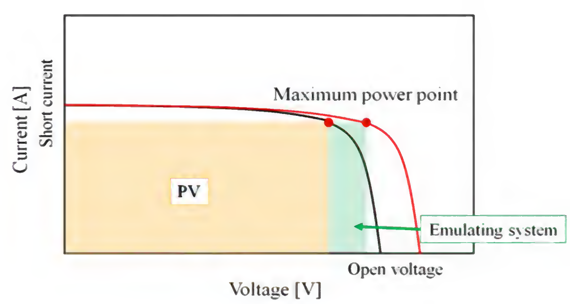

Fig. 6: V - I characteristic in series connection mode

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b. Control of off grid PV cell emulating system in series connection mode

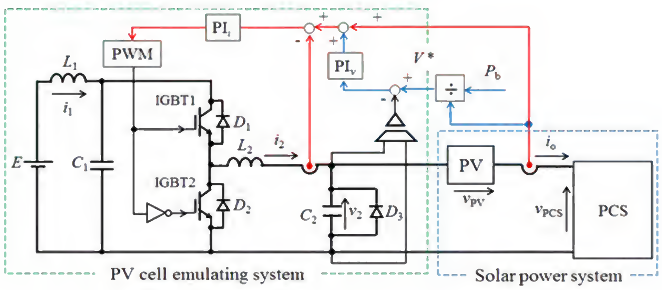

Fig. 7: Power converter circuit with old control design

The old control design of Power converter circuit of PV cell emulating system in series connection mode is shown in Fig. 7. The sum of output voltages of PV cell and the power convertor circuit is applied to the input voltage and must not exceed rated voltage of power conditioner. Therefore, the bi-directional chopper circuit is used as the step-down chopper to decrease the battery voltage. In the first stage, the small scale wind power generating system charges the battery. After the battery is fully charged, it disconnects with the small wind turbine.

Control structure is based on cascaded linear control loops, with a voltage control loop and a current control loop. Firstly, command voltage value V* is obtained by dividing the battery power P_b by the PV current i_o. The voltage loop controls the PV emulating system output voltage by comparing it with command voltage value V*. The voltage error is controlled using PI_v controller whose output is used to compute the command current for the current control loop.

Emulating system output current i_2 is controlled same with current i_o for PV because they are connected in series and the PV current i_o also is used to compute command current value of the emulating system output current i_2. The emulating system output current i_2 is measured for feedback to compute the current error, which is controlled by PI_i regulator. The output of the current control loop is the duty cycle reference of the bi-directional chopper circuit, which is modulated using carrier-based PWM. The resulting gate signal is used to control the switches of the bi-directional chopper circuit.

The analysis result (Fig. 8) of power converter circuit by state space averaging method shows that characteristics are changed significantly at the resonance frequency due to using inductor and capacitor. Thus, the transfer function of output current i_2 relating to the duty factor d of the PV cell emulating system is unstable.

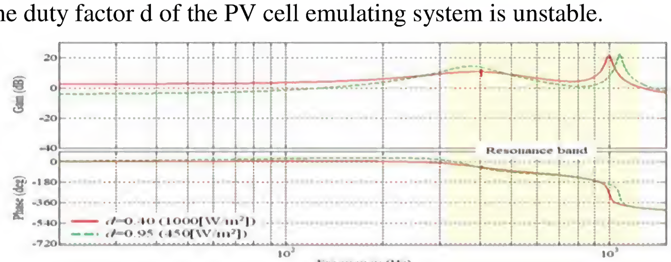

Fig. 8: Bode diagram of transfer function of output current relating to the duty factor of the PV cell emulating system

The derived frequency characteristic has resonance frequency because of the elements in circuit and operation of PV cells is changed by the irradiance. So, it can lead to instability due to change of the command value. Therefore, we consider resonance band to be suppressed by connecting a resistor. However, resistor can cause the voltage drop and power loss of the system. Thus, we propose the improved control circuit (Fig. 9) with virtual damping control to suppress the resonance band.

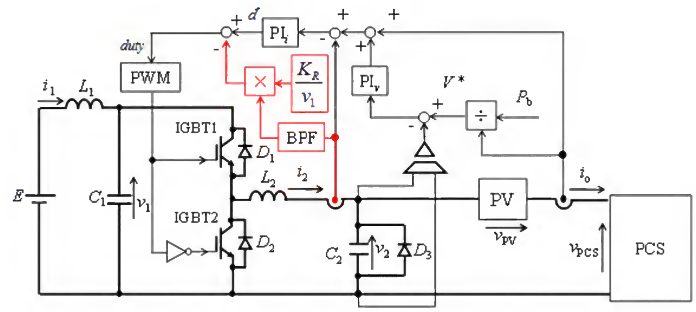

Fig. 9: Improved control circuit with Virtual damping control

Virtual damping control detects the output current i_2 to suppress a resonance frequency band component from the generated duty factor d*. Input duty factor of Pulse Width Modulation (PWM) switching as follows:

$$duty = d^* - (K_R i_2 / v_1) \quad (3)$$

with duty is duty factor of PWM switching; d* is duty factor in the controller PI_i; K_R is proportional gain to express damping resistance; i_2 and v_1 are output current and input voltage of PV cell emulating system.

By dint of applying virtual damping control, the resonance frequency is suppressed and the transfer function of output current i_2 relating to the duty factor d of the PV cell emulating system in series connection mode is stable (Fig. 10).

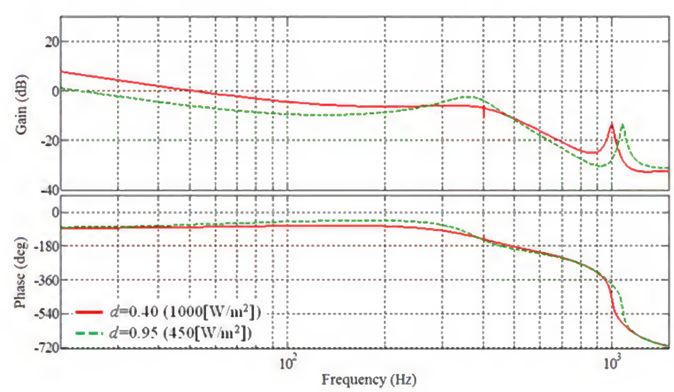

Fig. 10: Bode diagram of transfer function of output current relating to the duty factor of the PV cell emulating system with Virtual damping control

Results

We confirm operation of Grid tie PV cell emulating system in the stand alone mode and Off grid PV cell emulating system in series connection mode by PSIM software.

3.1. Grid tie PV cell emulating system in the stand alone mode

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Circuit of grid tie PV cell emulating system in the stand alone mode is shown in Fig.11. The PV cell emulating system is connected to the bi-direction DC/DC converter in boost mode which is used to perform the maximum power point tracking (MPPT) by Perturb and Observe (P&O) method [2]. The electrical energy at the output terminals of the PV cell emulating system is injected into the utility grid by grid tie DC/AC inverter. The four switches of grid tie DC/AC inverter are controlled by the method [3] that the instantaneous output current follows the reference current, as closely as possible.

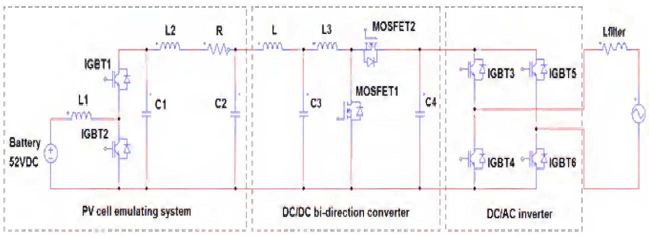

Fig. 11: Circuit of grid tie PV cell emulating system in the stand alone mode

The DC voltage from the PV cell emulating system is converted into AC voltage by DC/AC power inverter. The output voltage of PV cell emulating system is around 100 VDC while the single phase grid voltage is of 110Vrms. So, we need to increase the DC voltage up to around 200VDC before inverting the DC voltage to AC voltage. On inverting it to AC voltage, we get 155Vp (peak voltage) which is equivalent to 110Vrms. The PV cell emulating system is connected to the utility grid by a DC/AC full-bridge inverter with L type filter.

Fig. 12 shows the simulation result of output voltage and output current of PV cell emulating block that suits with the maximum power point voltage value of 100 V and maximum power point current value of 0.8 A in Table 1.

Table 1: System parameter for simulation

Parameter	Value
PV cell emulating control block	
Voltage of battery	52 VDC
Reference current of PV cell emulating control block	0.8 A
Inductor L1	10 mH
Inductor L2	2 mH
Capacitor C1	13.2 μF
Capacitor C2	15 μF
Resistor R	50 Ohm
P&O MPPT control block	
Capacitor C3	400 μF
Capacitor C4	300 μF
Inductor L	1 mH
Inductor L3	2 mH
Reference voltage of MPPT block	100 VDC
Grid tie control block	
Peak grid voltage	155 VAC
Grid frequency	50 Hz
Filter Inductor L filter	250 mH

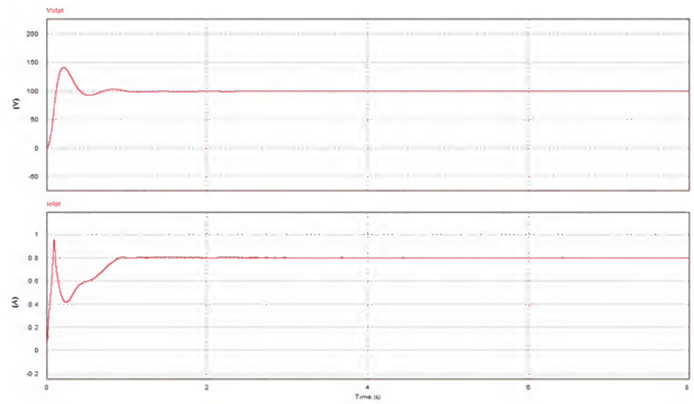

Fig. 12: Output voltage & output current of PV cell emulating block after low pass filter

Simulation result of output voltage and output current after the low pass filter of grid tie DC/AC inverter is shown in Fig. 13. The magnitude and frequency of the output voltage from the grid tie inverter are same with the grid voltage parameters while the output current is sinusoidal and in phase with the grid voltage. Thus, the PV cell emulating system can connect and transmit the power to the utility grid by the grid tie power conditioner.

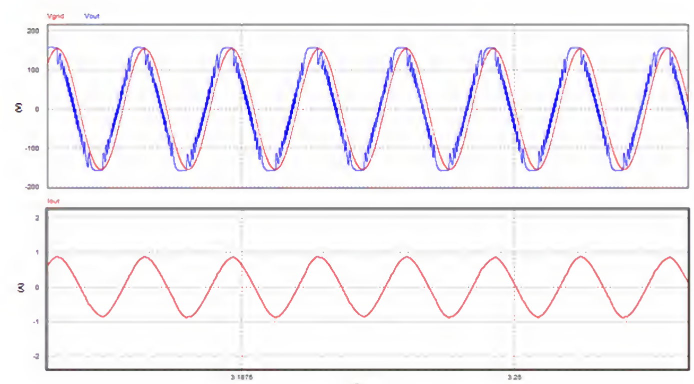

Fig. 13: Output voltage & output current of grid tie inverter after low pass filter

3.2. Off grid PV cell emulating system in series connection mode

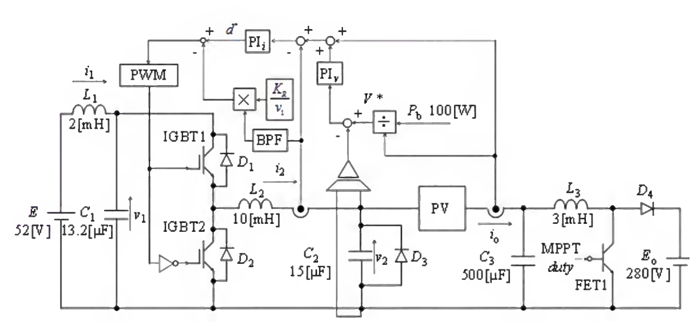

Fig.14: Circuit of Off grid PV cell emulating system in series connection mode

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The simulation circuit and element parameters are shown in Fig.14. Firstly, PV system generates power with MPPT control method and then it connects the emulating system in series mode. PV cell is operated under solar irradiation of 1000 W/m^2 while output voltage of Power conditioner system (PCS) is 280 VDC.

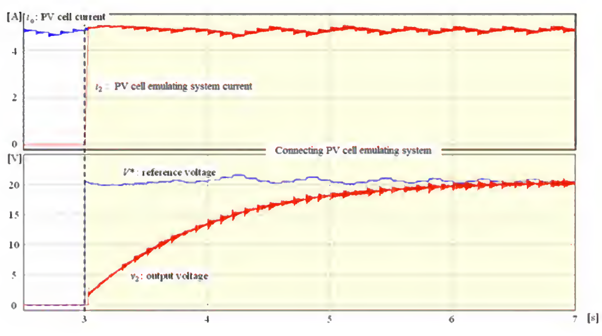

Fig.15: Output current and output voltage waveform of PV cell emulating system

Fig.15 shows the simulation result of output current i_2 and output voltage v_2 of the PV cell emulating system. Output current i_2 follows PV current i_o which is a command value in steady state. Output voltage value v_2 of the emulating system also matches the command voltage value V*. Thus, the emulating system output power can be transmitted to PCS.

The Fast Fourier transform (FFT) analysis in PSIM program of the emulating system output current i_2 in Fig.16 shows that resonance frequency band component is suppressed by virtual damping control with the reduction ratio of from about 0.078 to 0.02.

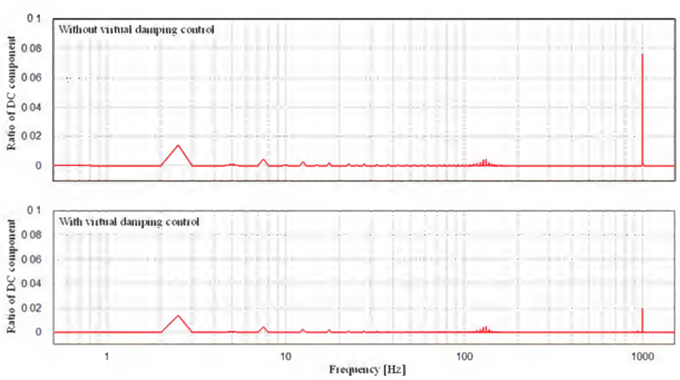

Fig.16: FFT analysis of emulating system output current

3. Conclusions

This paper has presented the operation of grid tie PV cell emulating system in the stand alone mode and improved control method for off grid PV cell emulating system in series connection mode. The simulation result shows that PV cell emulating system can connect and transmit the power to the utility grid by the grid tie power conditioner in case of PV cell cannot receive sunlight.

Besides, the emulating system can connect with PV cell in series mode to transfer power to off grid power conditioner because output current and output voltage of the PV cell emulating system can follow command current and voltage values in steady stage. The emulating system can use improved control circuit with virtual damping control to suppress the resonance band and the reduction ratio is from about 0.078 to 0.02.

In the future, we will verify operation of grid tie PV cell emulating system in the stand alone mode and off grid PV cell emulating system in series connection mode with experimental systems.

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